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Chapter 10

The Importance of Interconnection Technologies' Reliability of Power Electronic Packages

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Abstract

This chapter deals with the reliability of die interconnections used in plastic discrete power packages, dedicated to on-board electronic systems used in a wide range of applications such as automotive industry. A complete reliability analysis of two bonding technologies—aluminum wire and ribbon bonding—is proposed. This study is particularly focused on interconnection technologies' aging, when the package is subjected to thermal cycling or power cycling with high-temperature swings. For thermal cycling, the experimental reliability test results highlight that wire bond package aging is about 2.5 faster than the ribbon bond package. For power cycling, this acceleration factor is about 1.5. In both cases and whatever the bonding technique, the failure mechanism of the package is of a fatigue-stress nature. Many failure analysis results show wire bond lift-off. The degradation of the ribbon bond is more difficult to observe. Thermo-mechanical simulations using finite elements show a high stress concentration in the heel area. For the wire-bonding technique, the wire is subjected to repeated flexing and pulling that lead to its lift off. The ribbon-bonding process shows a higher robustness, thanks to a higher contact surface on the die, the low-loop profile and the stiffness of the ribbon.

Keywords: discrete power electronic packages, bonding techniques, wire and ribbon, thermal cycling, power cycling, reliability

1. Introduction

Over the last few years, due to the global energy crisis and the threat of climate change, transition toward a low carbon electricity system has increasingly become a major issue for all governments around the world [1, 2]. The Intergovernmental Panel on Climate Change (IPCC) has recently reported that greenhouse gas emissions, covered by the Kyoto Protocol, increased by 80% from 1970 to 2010. In particular, the IPCC has specified that the global

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energy consumption doubled over that period of time. In Europe, with about 20% of global emissions (excluding land use and forestry) in 2013, the transport industry is still a major contributor of greenhouse gases [3, 4].

Despite this worrying background and as pioneer in CO_2 emission reduction, European Union (EU) has strengthened its engagement with the development of an efficient and sustainable transport industry. In the automotive sector, electric vehicles (EVs) have gradually become popular over the past decade [5]. In recent years, hybrid EVs (HEVs) have been developed to combine the use of an internal combustion engine with one or more electric motors (EMs) connected to a battery pack. Such hybridization improves the fuel economy, but all of the available energy still comes from the fuel tank. Plug-in HEVs (PHEVs) have then been introduced to displace petroleum energy with multisource electrical energy. Therefore, PHEVs are able to draw power from the electric grid, store it in batteries, and use it for transportation [6]. These batteries play an important role due to their cost-effectiveness, energy and power densities, reliability, and charging time that depend on practical applications. In particular, the lifetime and charging duration strongly depend on the features of the battery charger.

Nowadays, power electronics plays an increasing role in the development of EVs. In particular, it is a key element of the traction inverter, the DC-DC converter used to supply the vehicle's onboard systems, as well as the battery charger [7]. But new important challenges are emerging, including a significant reduction in production costs, greater compactness, and cooling efficiency [8–10]. To achieve these goals, the packaging is of the utmost importance, because it ensures both electric connections of the chip and its power dissipation [11]. With excellent performance of existing power semiconductor devices, driven also by wide bandgap materials, the packaging typically acts as the main limiting factor [12, 13].

Thermal management of power packages is still an important issue to increase the system's lifetime [14]. In particular, it is important to limit thermal gradients and consequently thermomechanical stresses due to multi-physics couplings [15, 16]. The automotive market in Europe has largely adopted qualification according to the AEC-Q101 test flow for discrete components [17]. Such standard highlights that the lifetime has to be equal to 15 years when the power device is subjected to high-temperature variations. One way to address these needs consists in optimizing bonding technologies [18].

In this chapter, a comparative reliability study of two aluminum bonding technologies—wire bonding and ribbon bonding—is presented. At the moment, these bonding technologies are widely used for through-hole and surface-mount power packages. The reliability study focuses on both thermal-cycling and power-cycling tests.

2. Interconnection technologies for discrete power packages

2.1. Relevance of discrete packages in industrial applications

Packaging is an important step in the assembly process of an electronic chip. A package has the following main functions [19]:

- *Mechanical resistance and die protection*. The aim is to ensure the die disposing (as a function of package dimensions, shape, weight, etc.), and its mechanical and chemical protection against environment (vibrations, temperature variations, dust, moisture, etc.).
- *Consistence with the needs of the application*. A specific interest is granted to electrical properties (electrical insulation), heat transfer capacity, and protection against radiation.
- *Interface between the die and the electrical system (terminals)*.
- *Favorable costs*.

Nowadays, power semiconductor devices can be assembled into two kinds of packages: *discrete packages* and *power modules*. A discrete package contains only one die, while a power module is composed of several dies which are appropriately connected to build one or more basic functions. Although power modules are widely deployed today (e.g., automotive power train, aircraft power distribution, or railway traction inverters), where rated voltage and current can easily reach 6.5 kV and more than 1 kA, respectively, discrete power semiconductor devices still find numerous applications, and especially at power levels up to several kilowatts. D. O. Neacsu has recently highlighted that discrete power packages target the following markets [20]:

- IT (information technology) and consumer electronics for about 34%.
- Consumer appliances for about 30%.
- Industrial equipment for about 24%.
- Automotive for about 12%.

For most of these applications, manufacturing costs must be optimized to reach mass production. The discrete's cost per ampere will always be lower than that of a high-current module because this package is simple to manufacture facilitating series production.

2.2. Package manufacturing process and importance of die interconnections

The manufacturing process of a discrete power package (e.g., medium packages such as TO-220, D^{2}PAK, etc.) is composed of the following steps. First of all, a copper lead-frame constitutes the skeleton of the package. It provides both the heat-sink and the terminals (leads). For non-insulated package, the semiconductor die is directly soldered on the lead-frame. Regarding insulated package, a ceramic layer (e.g., alumina) is first soldered on the lead frame to provide insulation, either for safety reasons (if the end user can access the heat-sink) or functional considerations (if the heat-sink is connected to another potential). Then, the die is soldered on the ceramic. Whatever the package (insulated or not), all the layers are stacked up with lead-based solder alloys. These Pb-rich alloys are still used in industry due to the good trade-off between their low cost, and their good thermal and mechanical properties (melting temperature, wettability, thermal conductivity, and coefficient of thermal expansion). The interconnection between the die and the terminals can be done using several technologies: *wire bonding, clip bonding,* or *ribbon bonding*. These techniques will be described in the next sections of this chapter. Encapsulant is the final constituent of the package. Its main role is to protect the die and its interconnections against physical damage (shocks, vibrations, etc.) and external factors (temperature, humidity, etc.). Epoxy is currently the most commonly used organic-resin encapsulant material in use because it offers a beneficial mix of properties and thermal performances at a relatively low cost.

For applications in the low-voltage and high-current ranges, specific attention should be paid to die interconnections. These interconnections necessarily lead to electric resistance, and inductance which is important to minimize to reach performance requirements, especially in high-speed electronics. Their geometric dimensions are also a key factor to optimize.

2.3. Wire-bonding technology: scope and reliability limitations

2.3.1. Wire-bonding techniques

Wire bonding is the oldest and the most widespread technology used in industry because this is a straightforward, flexible, and cost-effective solution. Right now, it is estimated that over 90% of the manufactured packages in volume are wire bonded [21]. The wire-bonding technology consists in soldering a wire between two metal parts of the elements that must be interconnected, that is, the leads and the die metallization for a discrete power package. The most established wire materials are aluminum (Al), copper (Cu), and gold (Au) because of their high diffusion rates. For Al wires, some alloys (in the ppm range) can be used, either to harden aluminum (silicon or magnesium alloy) or to reduce corrosion (nickel alloy). Die metallization and wire must be made of the same material to prevent the formation of intermetallic layers.

Two basic techniques are currently used: *wedge wire bonding* and *ball wire bonding*. For each technique, there are three wire-bonding processes: *thermo-compression*, *thermo-sonic*, and *ultrasonic*. Wedge wire bonding typically uses the thermo-sonic and ultrasonic techniques depending on the application requirements, whereas ball wire bonding uses the thermo-compression and thermo-sonic processes.

Thermo-compression bonding requires high temperature (higher than 300°C) and force to deform wire and make bonds. The first wedge wire bonder, which was designed in the mid-twentieth century, used the thermo-compression method. Ultrasonic wedge wire bonding was then introduced in the early 1960s. This process, which combines force and ultrasonic power, is performed at room temperature. In comparison with thermo-compression bonding, the welding time is shorter. Thermo-sonic bonding consists in adjusting heat, force, and ultrasonic power to bond a wire. Nowadays, even if this process was first implemented in a wedge bonder in 1970, thermo-sonic bonding is typically used to bond a gold wire to either a gold or an aluminum surface on a substrate.

Among these three bonding processes, ultrasonic bonding is primarily used for Al wire in power electronics device applications (see **Figure 1**). In that case, the wire diameter range can easily reach 100–500 μm depending on the applications requirements (in particular, current-carrying capacity) and the process compatibility [22].

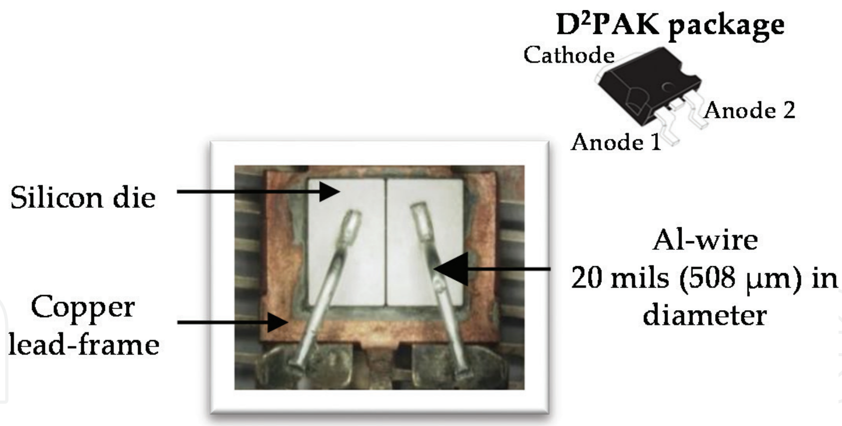

Figure 1. 2 × 20 A, 170-V Schottky diode assembled in a D²PAK package using Al-wire bonding.

2.3.2. Reliability issues

Many authors have highlighted that wire-bonding failures of power packages are mainly caused either by shear stresses generated between the die and the wire, or due to repeated flexure of the wire. Two main failure mechanisms can particularly occur: *wire bonding lift-off* and *heel cracking* [23–26].

Wire bond lift-off (see **Figure 2**) occurs due to crack propagation along the interface between the wire and the die. The initiation of a fracture mechanism within the wire tail itself is responsible for the crack development. Its propagation is thermally activated. In particular, during active or passive temperature cycling, the CTE (coefficient of thermal expansion) mismatch between the wire bond material (e.g., aluminum) and die material (e.g., silicon) induces the crack propagation that finally leads to the wire bond lift-off. Many studies have reported the numerical methods to calculate such strength applied onto the wire. Many authors have also reported that it is possible to strengthen wire bond reliability by gluing the wire to the die metallization using a coating layer (e.g., a polyimide cover layer).

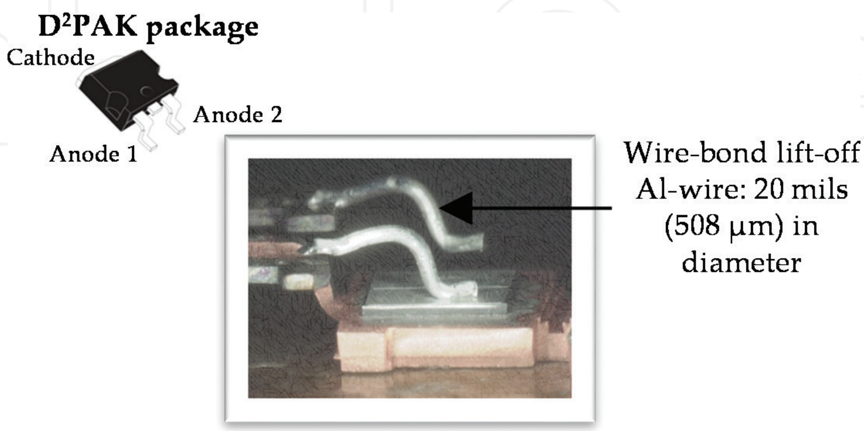

Figure 2. Aluminum wire bond lift-off (2 × 20 A, 170-V Schottky diode assembled in a D²PAK package).

Heel cracking is amplified by temperature cycling. In that case, a crack propagation occurs at the wire heel (see **Figure 3**). This phenomenon can lead to partial wire disconnection. As a consequence, the electrical conductivity is not completely achieved. As widely reported in the literature, when a wire bond is subjected to thermal cycles, the wire dilatation induces a flexure. For example, 50°C temperature swing can produce a 10-μm increase of length. However, because the wire is bonded on a metallization layer, it leads to 0.05° additional angle face to the bonded region.

2.4. Clip-bonding technology

Clip interconnection may be an alternative to wire bonding because it is a "bond-less" packaging technology. This technique consists in connecting the active area of a die to the package lead frame using a small metal slab which is directly soldered on die's top surface. At the moment, a solid copper bridge, also called "clip," is widely used in discrete power packages (see **Figure 4**) [27].

Copper clip bonding allows both larger possible contact area and lower on-resistance than wires. For example, on a MOSFET (metal-oxide-silicon field effect transistor) device, one copper clip may replace 15 gold wires. In that case, the static drain-source on-resistance ($R_{DS(on)}$) can be reduced by about 30%, while, at the same time, providing an improved current distribution into the device [28].

Clip bonding helps to strengthen the thermal behavior of a power package by providing efficient thermal dissipation from the top of the die to the lead-frame. Therefore, the maximum junction temperature during power device operation can be optimized, which is a key parameter to manage in order to extend its operation life and reliability [29].

Despite these clear advantages, the clip-bonding technology has some drawbacks. A major disadvantage is particularly related to the chemical aspects of the clip soldering. The clip is typically reflow soldered to the die and substrate pads. After clip bonding, it is very important to remove flux residues. This means that the cleaning agent must chemically match the properties of solder paste residues. Thus, special attention should be paid to ensuring a high-reliability bonding process [30].

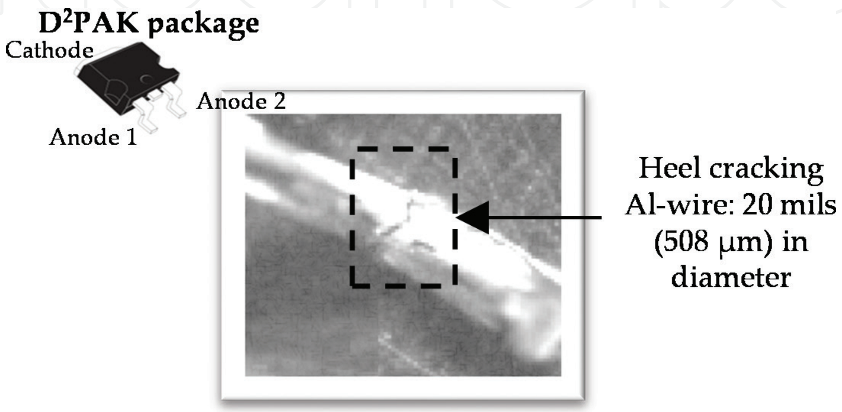

Figure 3. Aluminum wire heel cracking (2 × 20 A, 170-V Schottky diode assembled in a D^2PAK package).

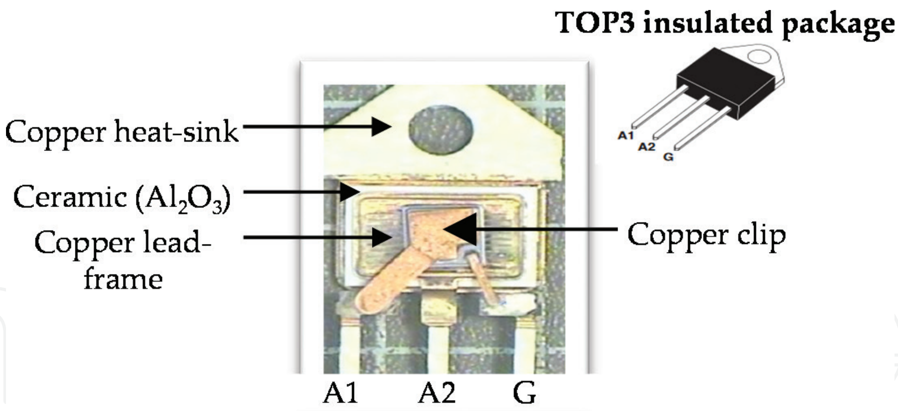

Figure 4. 25 A, 1200-V Triac assembled in a TOP3 insulated package using copper clip bonding.

2.5. Ribbon bonding as the most efficient and cost-effective interconnection technology

Today's industrial applications require higher current density in electronic power devices. These devices are implemented in more and more compact, lightweight, energy efficient, and cost-effective on-board systems. Die-interconnection technologies have a key role to play in achieving these objectives. They must above all warrant the electrical, thermal, and mechanical stability of the whole package. Their process conditions must also be controlled, stable, reliable, and cost effective.

Ribbon bonds represent currently a very attractive solution for power electronic applications that carry high electrical loads [31–33]. The process consists in interconnecting a semiconductor die to a lead in a power package using a flexible conductive ribbon (see **Figure 5**). Aluminum as interconnect material offers a good compromise between electrical performances (in particular, on-resistance) and cost. Ultrasonic technology is typically used because of its main strengths such as high flexibility and reliability, low cost, and increased productivity.

Compared to aluminum wire bonding, aluminum ribbon bond helps to replace a significant number of parallel wires per device to fulfill the current or necessary on-resistance requirements. For example, one aluminum ribbon (width and thickness equal to 60 mils (1524 μm)

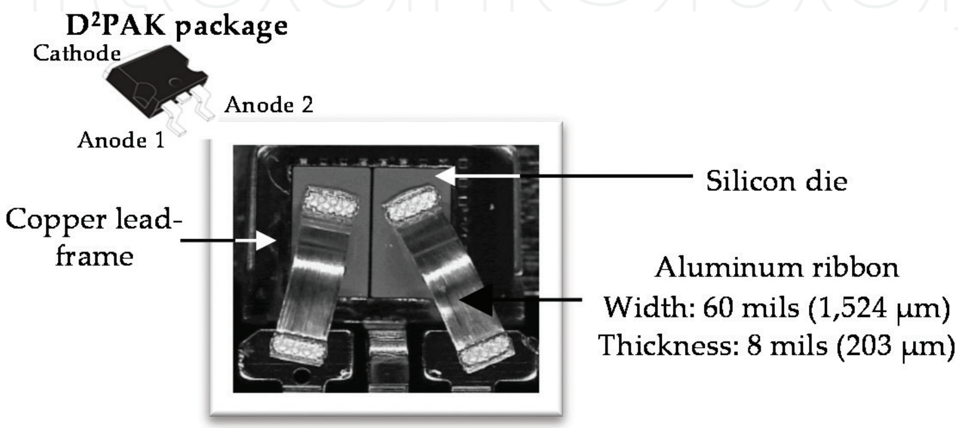

Figure 5. 2 × 20 A, 170-V Schottky diode assembled in a D²PAK package using Al-ribbon bonding.

and 8 mils (203 μm), respectively) can replace about two aluminum wires (20 mils (508 μm) in diameter) [34]. In that case, the ribbon limits the risk of non-continuous contact area and inhomogeneous heat dissipation in comparison with multiple wire bonds. Moreover, the high cross-sectional area of aluminum ribbon bond limits parasitic resistances and inductances which can lead to additional losses, especially in high-frequency-switching applications.

3. Relevance of aluminum ribbon bonding in temperature-cycling applications

3.1. Methodology

3.1.1. Experimental reliability test procedure

A power Schottky diode (2 × 20 A, 170 V, 175°C maximum junction temperature) assembled in a D²PAK package was chosen as a test device for the reliability analysis. Two kinds of experimental tests were performed: *thermal cycling* (passive temperature cycling) and *power cycling* (active temperature cycling). Each test was based on automotive qualification documents such as the AEC-Q101 standard [35]. In particular, this standard describes the cyclic temperature profiles. For thermal cycling, the test conditions are as follows: −65°C/+150°C (ΔT_j = 215°C), two cycles per hour, 1000 cycles. Regarding power cycling, the devices must be subjected to a junction temperature mismatch at least equal to 100°C during 8572 cycles (one cycle lasts 7 min).

For each test, two sets of samples were used. The first one was composed of 77 units manufactured using the aluminum wire-bonding technique (20 mils (508 μm) in diameter). The second one was composed of 77 devices under test manufactured using the aluminum ribbon-bonding process (width and thickness equal to 60 mils (1524 μm) and 8 mils (203 μm), respectively). It is important to note that all devices under test had the same die size (4.87 mm × 4.24 mm × 280 μm).

Several readouts were carried out during the experimental reliability tests. This means that all units were removed from the test bench at several fixed time intervals. For thermal cycling, the readouts were 100 cycles, 500 cycles, 1000 cycles, 1250 cycles, and 2000 cycles. Regarding power cycling, the devices under test were removed at 4286 cycles and 8572 cycles. For each duration mentioned earlier, the following electrical and thermal parameters were measured for each unit under test: forward voltage drop (V_F), reverse leakage current (I_R), and junction-to-case thermal resistance ($R_{th(j\text{-}c)}$).

For both sets (the first one using the Al-wire-bonding technique and the second one using the Al-ribbon-bonding process), the evolution of each parameter (in relation to the number of passive or active temperature cycles) can be shown on a normal probability plot (Henry's chart). This chart is typically used to extract the mean and standard deviation of the statistical distribution. Regarding the targeted failure mechanism (bond lift-off), we only focused on the V_F-parameter. In particular, its evolution decided when a power device reached its end of life. This parameter was evaluated using the temperature dependence of the forward voltage drop. Regarding the initial V_F-values, both sets of 77 units under test were homogeneous before the reliability test launching (average value and standard deviation equal to 0.85 V for 40-A forward current and 5 mV, respectively). The failure criterion we took into consideration was a V_F-parameter increase higher than 5% with respect to its initial value. This failure criterion is severe as compared to that of the AEC-Q101 standard, for which allowable shift values within ±20% of the initial readings are tolerated [35]. This aims to establish a reliability analysis as quickly as possible (considering the duration of the passive or active temperature-cycling tests).

3.1.2. FEM thermo-mechanical modeling

Thermo-mechanical simulations (for instance, with ANSYS® Workbench software) using the FEM (finite-element method) are commonly used to get a better understanding of devices' failure mechanism.

In this study, a three-dimensional model of the D²PAK package was generated. As mentioned previously, the test device was composed of two Schottky diodes. However, one diode was only taken into consideration to simplify the modeling and optimize the simulation durations. The numerical model was composed of quadrilateral meshed elements with a refined meshing at the wire and especially the heel, as well as the contact area between the silicon die and the wire (see **Figure 6**). The highest element edge length was equal to 200 μm and the lowest one was equal to 20 μm.

The thermo-mechanical properties of the materials are summarized in **Tables 1** and **2** [14]. Regarding the thermal loads, the passive temperature-cycle profile (−65°C/+150°C, rise time, fall time, and cycle duration equal to 15, 15, and 30 min, respectively) was used. For power cycling, a heat flow was adjusted to meet the junction temperature profile described in the previous paragraph. Regarding the mechanical loads, the *X*-, *Y*-, and *Z*-displacements were blocked at the origin of the plan to freely authorize the expansion of materials

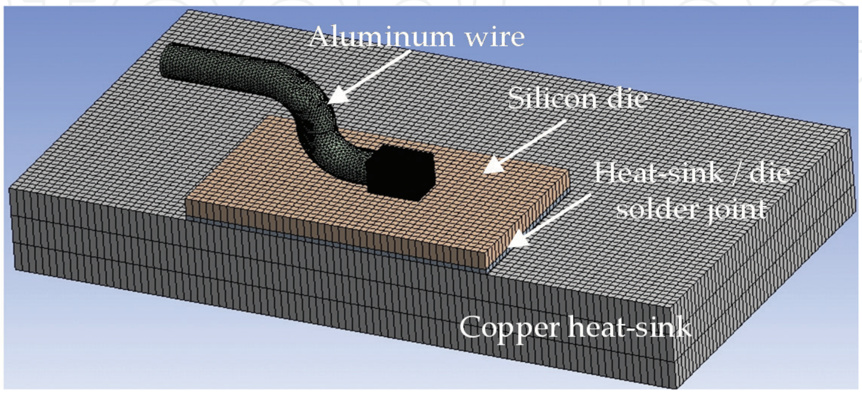

Figure 6. FEM model of the D²PAK package (an example of assembly using Al-wire-bonding process).

	Dimensions	Thermal conductivity ($W.m^{-1}.K^{-1}$)	Specific heat ($J.kg^{-1}.K^{-1}$)	Density ($kg.m^{-3}$)
Copper heat-sink	10.4 × 10.75 × 1.36 mm	330	385	8900
Al wire	508 µm in diameter	195–0.059 T	920	2680
Al ribbon	Width and thickness equal to 1524 and 203 µm, respectively			
Silicon die	4.87 × 4.24 × 280 µm	156	703	2330
Epoxy resin	10.4 × 9.35 × 4.60 mm	0.75	800	1820
Solder joint ($PbSn_5Ag_{2.5}$)	4.87 mm × 4.24 mm × 15 µm	44	130	11,070

Table 1. Typical thermal data of D^2PAK materials [14].

3.2. Main results and discussion

3.2.1. Reliability analysis

For each reliability test and each set of samples, the distribution of the units' lifetime was fitted with a two-parameter Weibull distribution. At the moment, this law is widely used in reliability engineering due to its versatility and relative simplicity.

From the Weibull cumulative probability density function (*cdf*), in accordance with Eq. (1), it is possible to extract the characteristic lifetime (η) at which 63.2% of the devices under test in a set failed, and the shape parameter (β) is also known as the Weibull slope

$$F(t) = cdf = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{1}$$

- t: time to failure.
- η: characteristic lifetime ($F(t) = 63.2\%$).
- β: shape parameter (Weibull slope).

For both reliability tests (thermal cycling and power cycling), the two-parameter Weibull analysis is presented in **Figure 7**. **Figure 7** highlights that the D^2PAK package failure mode

	Young's modulus (GPa)	Poisson's ratio	CTE (10^{-6} K^{-1})
Copper heat-sink	120	0.34	16.8
Al wire/ribbon	64	0.3	23
Silicon die	130	0.28	2.6
Epoxy resin	16.5	0.3	19
Solder joint ($PbSn_5Ag_{2.5}$)	20.9–0.04 × T (°C)	0.3	27

Table 2. Typical mechanical data of D^2PAK materials [14].

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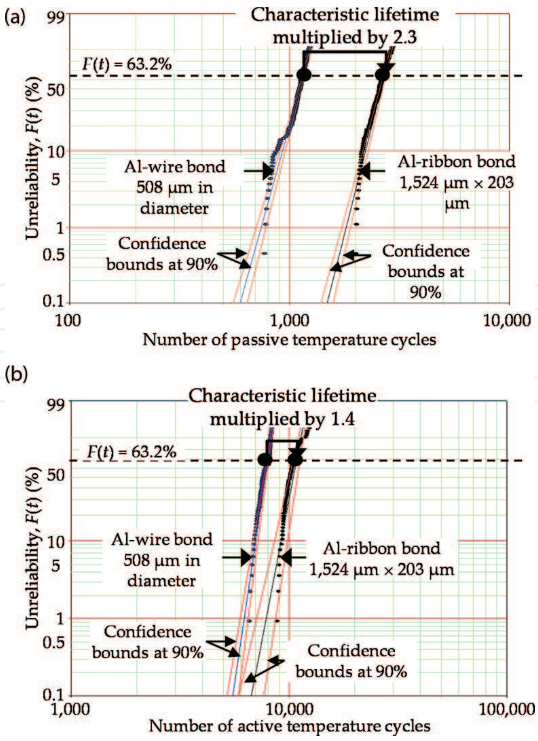

Figure 7. Relevance of Al-ribbon-bonding reliability during thermal cycling (a) and power cycling (b).

is of a fatigue-stress nature because the shape parameter (β) is higher than one, whatever the bonding technique used. For the thermal-cycling tests (see **Figure 7(a)**), the β-values of the units using Al-wire bonding and Al-ribbon bonding are about 10.5 and 11.5, respectively. Regarding the power-cycling tests (see **Figure 7(b)**), the β-values of the units using Al-wire bonding and Al-ribbon bonding are about 19.2 and 14.8, respectively. Many failure analysis results show the expected failure mechanism, that is, wire bond lift-off as described in **Figure 2**.

For the thermal-cycling tests, **Figure 7(a)** shows that the characteristic lifetime (η_2) of the D^2PAK assembly using the Al-ribbon-bonding process is about 2.3 times higher than the units using the Al-wire-bonding technique (Al-wire bonding: $\eta_1 \approx 1{,}155$ cycles; Al-ribbon bonding: $\eta_2 \approx 2{,}702$ cycles). Therefore, the failure acceleration of the wire bond package is more than two times higher than the ribbon bond package.

Regarding the power-cycling tests, **Figure 7(b)** shows that the characteristic lifetime (η_4) of the D^2PAK assembly using the Al-ribbon-bonding process is about 1.4 times higher than that of the units using the Al-wire-bonding technique (Al-wire bonding: $\eta_3 \approx 7{,}899$ cycles; Al-ribbon bonding: $\eta_4 \approx 10{,}704$ cycles). Thus, the failure acceleration of the wire bond package is about 1.5 times higher than that of the ribbon bond package.

3.2.2. Failure mechanism understanding

This part of the paper focuses on the wire bond lift-off explanation since the degradation of the ribbon bond is more difficult to observe. In the latter case, the number of thermal cycles

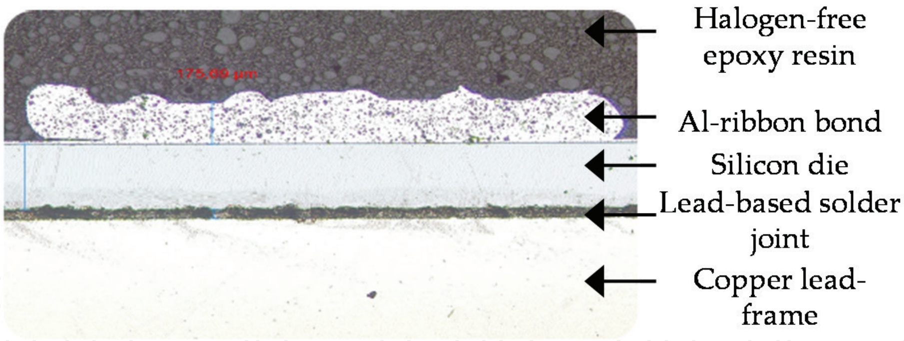

Figure 8. Failure analysis result of a D²PAK package using Al-ribbon bonding after 2000 passive temperature cycles (−65℃/+150℃, two cycles/h).

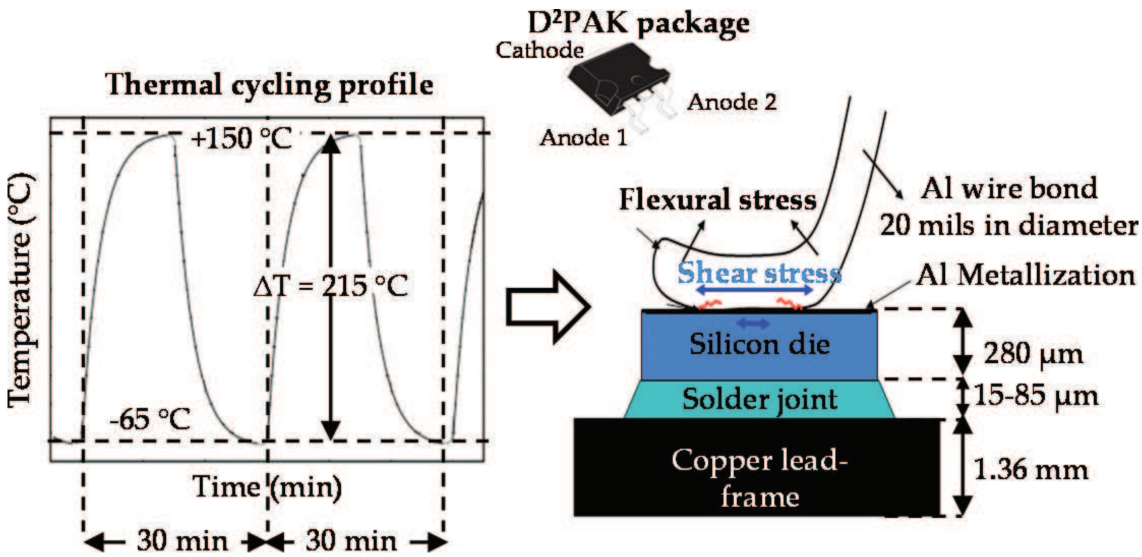

Figure 9. Fatigue mechanism explanation of Al-wire bond subjected to high-temperature swings.

must be much higher to have the same failure mechanism. For example, as can be seen in **Figure 8**, for thermal cycling, the ribbon bond lift-off phenomenon cannot be observed, even after 2000 temperature cycles.

The temperature cycles are connected to the stress cycles at the link between the wire and the die. As can be seen in **Figure 9**, the fatigue mechanism is likely due to two phenomena. The first one corresponds to the wire flexure at the bond heel. Indeed, repeated flexing and pulling of the wire occur as the Schottky diode heats and cools during temperature cycling, due to temperature swings. This phenomenon has already been widely described. For example, Meyyappan *et al.* developed a wire fatigue model to predict failure due to flexure in wedge-bonded power modules [36].

The Von Mises stress can typically be used to determine whether an isotropic and ductile material (such as aluminum) will yield when subjected to a complex loading condition. This is accomplished by calculating the Von Mises yield criterion and comparing it to the material's yield stress. **Figure 10** shows the Von Mises stress distribution after one passive temperature cycle (−65℃/+150℃. Rise time, fall time, and cycle duration equal to 15, 15, and 30 min, respectively). The aluminum wire exhibits some stress concentration in the heel.

The wire bond lift-off is also initiated by a thermo-mechanical stress (shear stress) caused by the CTE mismatch between the aluminum bond wire (CTE_{Al} = 23.8 ppm.℃$^{-1}$) and the silicon die (CTE_{Si} = 2.6 ppm.℃$^{-1}$). The number of thermal cycles to failure (N_f) is proportional to the maximum strain amplitude ($\Delta\varepsilon$), which depends on the CTE mismatch and the temperature swing (ΔT) in accordance with Eq. (2)

$$N_f \propto \Delta\varepsilon = (CTE_{Al} - CTE_{Si})\Delta T \quad (2)$$

- N_f: number of thermal cycles to failure.
- Δc: maximum strain amplitude.
- ΔT: temperature swing.
- CTE_{Al} = 23.8 ppm.°C^{-1}. CTE_{Si} = 2.6 ppm.°C^{-1}.

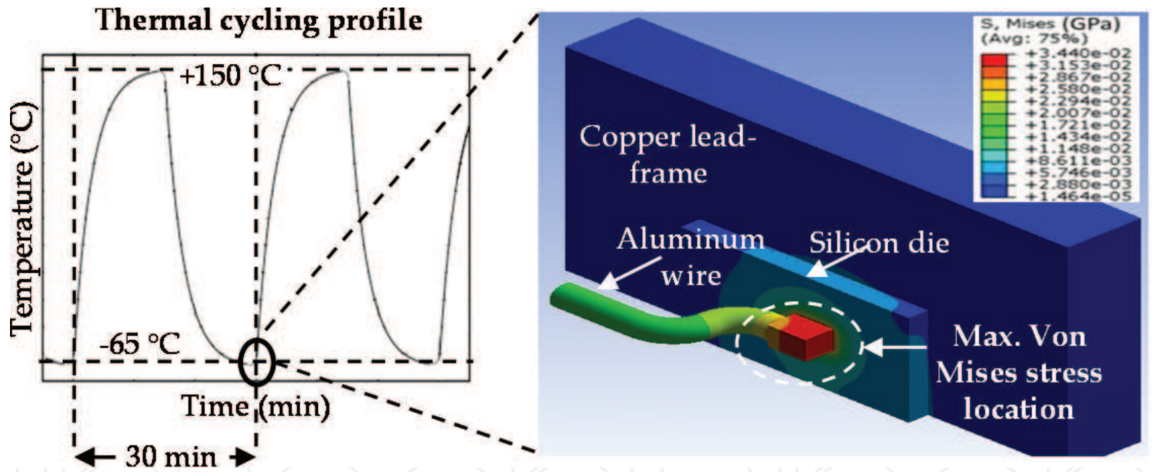

Figure 10. Example of Von Mises stress distribution after one passive temperature cycle (−65°C/+150°C, two cycles/h, D²PAK package using Al-wire-bonding process).

The failure analysis results highlight that the bonding rupture starts to progress laterally, finally causing the bond wire to lift off.

The Schottky diodes assembled in a D²PAK package using the Al ribbon-bonding process exhibit a better robustness during thermal cycling. Their characteristic lifetime is about 2.3 times higher than the D²PAK units that use the Al wire-bonding technique. A higher contact surface on the silicon die, the low-loop profile, and the stiffness of the ribbon may allow slowing down crack initiation and propagation between the Al bond and the Al metallization on top of the silicon die.

4. Conclusions

This chapter has pointed out the relevance of aluminum (Al) ribbon bonding used in the assembly process of discrete power packages. The reliability analysis has been particularly performed on a surface-mount device (D^2PAK assembly) subjected to thermal cycling and power cycling. For example, at the moment, such package is widely used in automotive applications.

To assess the good performances of Al-ribbon bonding, the reliability analysis has been based on a comparative study between Al-wire bonding and Al-ribbon bonding.

For both thermal cycling and power cycling, the Weibull analysis has highlighted that the failure mode of the D^2PAK package is of a fatigue-stress nature, whatever the bonding technique used. Many failure analysis results have shown wire bond lift-off. The degradation of the ribbon bond is more difficult to observe.

Regarding thermal cycling, the experimental test results have also shown that failure acceleration of the wire bond package is about 2.5 times higher than that of the ribbon bond package. For power cycling, this acceleration factor is about 1.5.

Thermo-mechanical simulations using finite elements have shown that a stress concentration can be observed in the heel area. For the wire-bonding technique, the wire is subjected to repeated flexing and pulling that lead to the wire lift-off. The ribbon-bonding process shows a higher robustness. It can be explained by a higher contact surface on the die, the low-loop profile, and the stiffness of the ribbon.

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